DESIGN INFORMATION AND GUIDE FOR CORROSION CONTROL OF STEEL USED FOR UNDERGROUND INSTALLATIONS

(a) Introduction

The following discussions and outlined design information are recommended for design of systems of corrosion control on steel pipes installed in soils encountered in Nebraska.

The discussion and design procedure outlined herein are aimed primarily at corrugated metal pipe, since we have very few welded or rolled steel pipe installations in Nebraska for any purpose except wells.

Standard analysis and design procedures, as recommended by Soil Conservation Service Design Note 12, Harco's notes on magnesium anode design, Peabody, and others, are followed. However, some formulas are modified slightly to make the design more compatible to observed results of installations on over 100 systems on dams in Nebraska. While the variations were noted previously, the documentation for adjusting the formulas for current needs was primarily based on 44 sites selected as representative because they were more than 5 years old and in soils with resistivities ranging from 800 ohms to over 2,000 ohms.

(b) Defining The Electrolytic Corrosion Problem

The three main recognized factors of corrosion of underground installations are: 1) soil acidity, 2) soil resistivity, and 3) stray or induced currents. These may be summarized as follows:

(1) The pH of Nebraska soils is not a major factor, since the soils have a pH of 6 or higher with most near the neutral of 7.0. A few soils have pH's high enough that protection by deposition of salts is occurring.

(2) The resistivity of the soil (ohm/cm) is the best indicator of the potential for corrosion of a CMP installed in moist to saturated conditions.

The relative effect of soil resistivity can be further defined by ranges of resistivity as:

- Over 4,000-ohm soil has little or no adverse effect on zinc-coated CMP with life expectancy of over 30 years.
- In 4,000-ohm to 2,500-ohm soils, zinc-coated CMP normally will last 25 years or longer.

  Asphalt coating, or the 'plastic' coating, in addition to zinc, will extend the life 10 years or more. Cathodic protection should be considered for useful life beyond 30 to 40 years when a CMP is installed in soils in this resistivity range.
- In 2,500-ohm to 1,500-ohm soils, CMP will require a coating in addition to the zinc coating for a 20- to 25-year life expectancy.

  Magnesium anodes will be installed at the time of construction to extend life beyond 20 to 25 years.
- Soils below 1,500 ohms' resistivity are quite corrosive; therefore, both additional coating (either asphalt or 'plastic') and anodes will be necessary to assure a life beyond 5 or 10 years for the zinc-coated CMP.

(3) The induced current problems are minimal due to the location of Soil Conservation Service structures. When they exist, the design will require special analysis outside the scope of this guide.

(c) Corrosion Prevention

Corrugated metal pipe protection requires consideration of several variables. Some of these are: 1) the life desired from the works, 2) the corrosive potential of the soils in terms of resistivity and acidity, and 3) costs of installation and replacement of the pipe with or without protection.

(d) Coating

Coating used on CMP is basically three types: 1) zinc-coated (2 oz/ft^2); 2) zinc-coated, asphalt-dipped or asbestos-impregnated, zinc-asphalt dipped[1]; and 3) zinc-coated, pitch resin, or polymer-coated.

All CMP approved for installation in Nebraska will have 2 ounces of zinc coating. The zinc, in addition to protecting the steel from direct contact with surrounding soil, acts as a sacrificial anode to protect the steel. The asphalt coating provides a further separation of pipe and soil along with some limited dielectric properties. The pitch resin or polymer coating provides the separation barrier along with fair to good dielectric properties.

(e) Design Analysis

Once the determination has been made, based on soil resistivity, design life and other factors, that cathodic protection is needed, the design follows three basic steps.

The first step for design of any cathodic protection system is to estimate the amount of current needed. The basic formula, as modified based on field tests, is:

$$It_{ma} = \frac{CA}{\mathrm{Re}\left(\frac{RE}{1000}\right)^{0.3}}$$

where: It_{ma} = total current required to protect the metal

- C = constant for quality of pipe coating over the zinc plating where C = 60 for coal tar, pitch resin, or equals for a Class "B" coating; C = 90 for polymer coating (10 mil); C - 120 for asphalt coating
- A = area of metal to be protected
- Re = field-measured resistivity of the soils in which the pipe is or will be placed

The variables of type or quality of coating and the soils' resistivity for the above formula have been reduced to the graphs on Figure 1 except for the variable "A". So the formula now becomes:

$$It_{ma} = \mathrm{Im}a\ (fromFig.1)\ X\ A$$

The second step of designing a cathodic protection system, using magnesium anodes, is to determine size and number of anodes needed.

The output of the magnesium anode is a function of 1) anode length and diameter, 2) resistivity of the soil around the anode, 3) quality of the pipe coating, 4) potential of the pipe to soil (as measured by the $CuCuSO_4$ half-cell), and 5) the number of anodes in parallel.

The chart of anode output versus soil resistivity (Fig. 2) uses the formula:

$$I_{anode} = \frac{K * f * Ps * Adj}{\mathrm{Re}}$$

where I_{anode} = minimum capability of the anode in milliamps

- K = a constant for a magnesium alloy of Grade III or better; (adding a 50% safety factor and allowing for

[1] While asbestos-impregnated, asphalt-coated pipe does retain the asphalt coating better, there is little difference in the corrosion resistance between this and plain asphalt coating.

pipe to soil plus circuit resistance, use K = 60,000)

f = factor for anode length and diameter; (use '1.0' for 17 lb, '1.06' for 32 lb, '0.71' for 9 lb, '0.60' for 5 lb anodes)

Ps = correction for level of pipe to soil potential; (use -0.90 volts as level desired and Ps = 0.93)

Adj = adjustment for the number in parallel; (using a factor of 0.95 will result in less than 5% error for 1, 2, or 3 anodes in parallel on 10 ft or more spacing)

The total output of an anode, then, is the number of anodes times the output per anode. A recommended installation for a principal spillway in a structure would be two anode beds, one near each end of the pipe, each with its own junction box. One to four separate beds, depending on needs, is acceptable design. Due to maintenance problems, especially with underground connections, it is desirable to limit the number of anodes per bed to three or less and use more beds.

The third step of the design is the check of the design life. The formula

$$Y = \frac{47\,Wt}{It_{ma}}$$

is used, where

Y = years of anticipated life

Wt = total weight of magnesium anodes

It_{ma} = designed current needed

47 = 116 theoretical amp yrs/lb magnesium x 50% efficiency x 80% utilization factor

The nomograph of Figure 3 is based on this formula; however, it is important to remember that-the mass of an anode, as compared to the area, also affects the useful life of an anode. The utilization factor can be less than 20% with time as an anode becomes passive or dissipated by reaction with the soil. The larger anodes will function longer due to their bulk factor. The maximum that can be expected from an anode bed, therefore, is limited by the individual anode size as well as the total pounds of magnesium in the bed. The normal maximum life expectancy should be: for 5-lb anodes, 12 years; for 9-lb anodes, 15 years; 27-lb anodes, 25 years; 32-lb anodes, 35 years.

Example:

Re = Soil resistivity of 1200 ohm/cm from the 4 pin field tests

(Since the soil resistivity is less than 1500 ohms, plan to use 10 mil PVC coating)

A = Area of 10' x 42" riser + 100' x 30" barrel + 2 6'x6' diaphragms (one side) = 967 ft^2

Design

life = 25 years

From Figure 1, at Re = 1200 ohms and C = 90 for polyvinyl-coated pipe, $Ima/ft^2 = 0.07$. Total It_{ma} needed = 0.07 ma/ft^2 x 962 ft^2 = 67 milliamps.

From Figure 2, select the anode combination that will produce the current need. For this example, either three 9-lb, two 17-lb, or two 32-lb anodes will provide the current.

From Figure 3, the three 9-lb anodes will need to be replaced before the design life of 25 years; the two 17-lb anodes will provide the 25-year life with resistors to control current flow; the two 32-lb anodes would provide protection to 40 years.

The two 17-lb anodes appear to be the best combination if the system will be monitored regularly and resistance added as needed to maintain a current usage below 70 ma. If monitoring may be irregular, the two 32-lb anodes would be the better choice.

FIGURE I

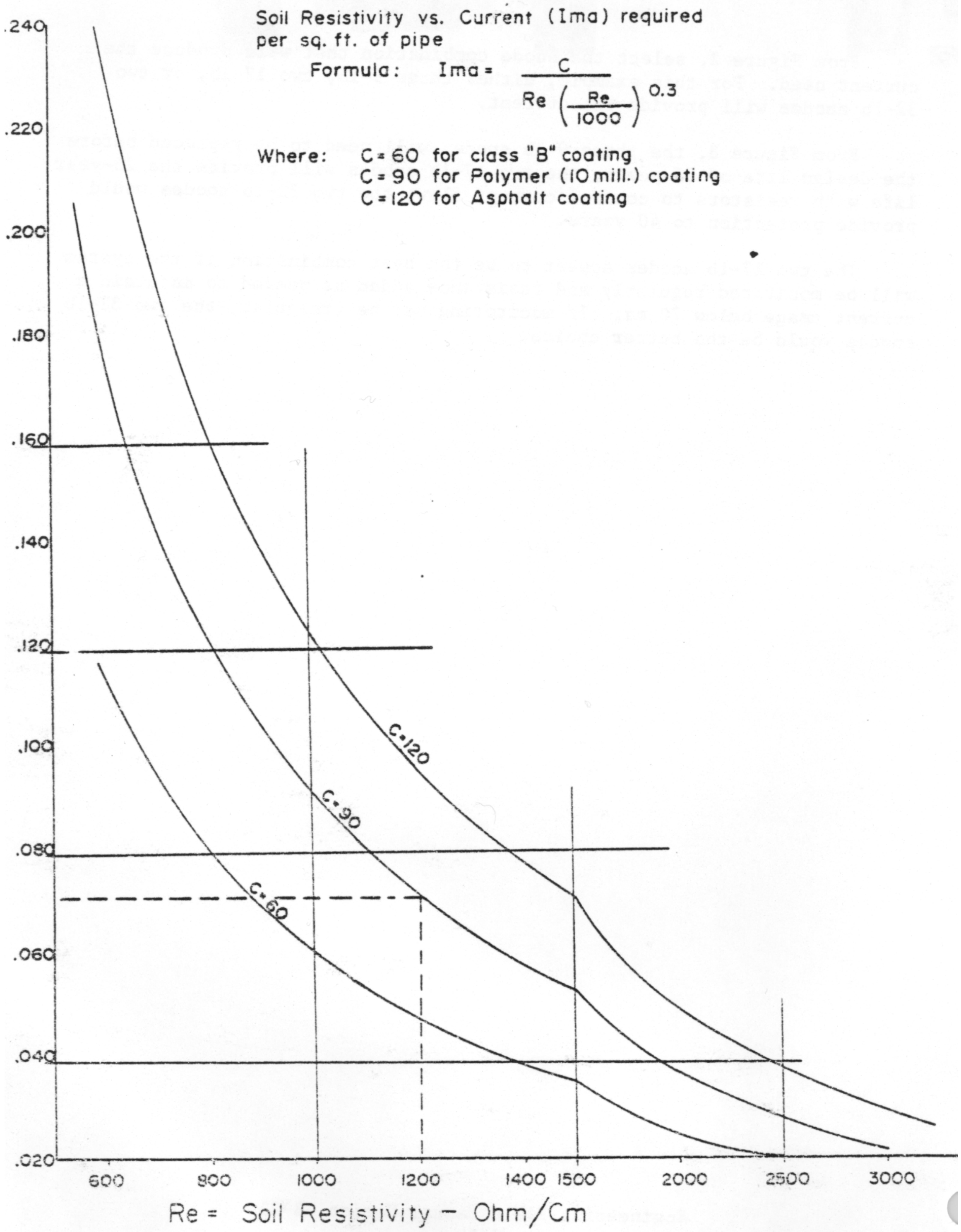

Soil Resistivity vs. Current (Ima) required per sq. ft. of pipe
Formula: $Ima = \dfrac{C}{Re\left(\dfrac{Re}{1000}\right)^{0.3}}$
Where: C = 60 for class "B" coating
C = 90 for Polymer (10 mill.) coating
C = 120 for Asphalt coating
.240
.220
.200
.180
.160
.140
.120
.100
.080
.060
.040
.020
C=120
C=90
C=60
600
800
1000
1200
1400
1500
2000
2500
3000
Re = Soil Resistivity – Ohm/Cm

FIGURE 2

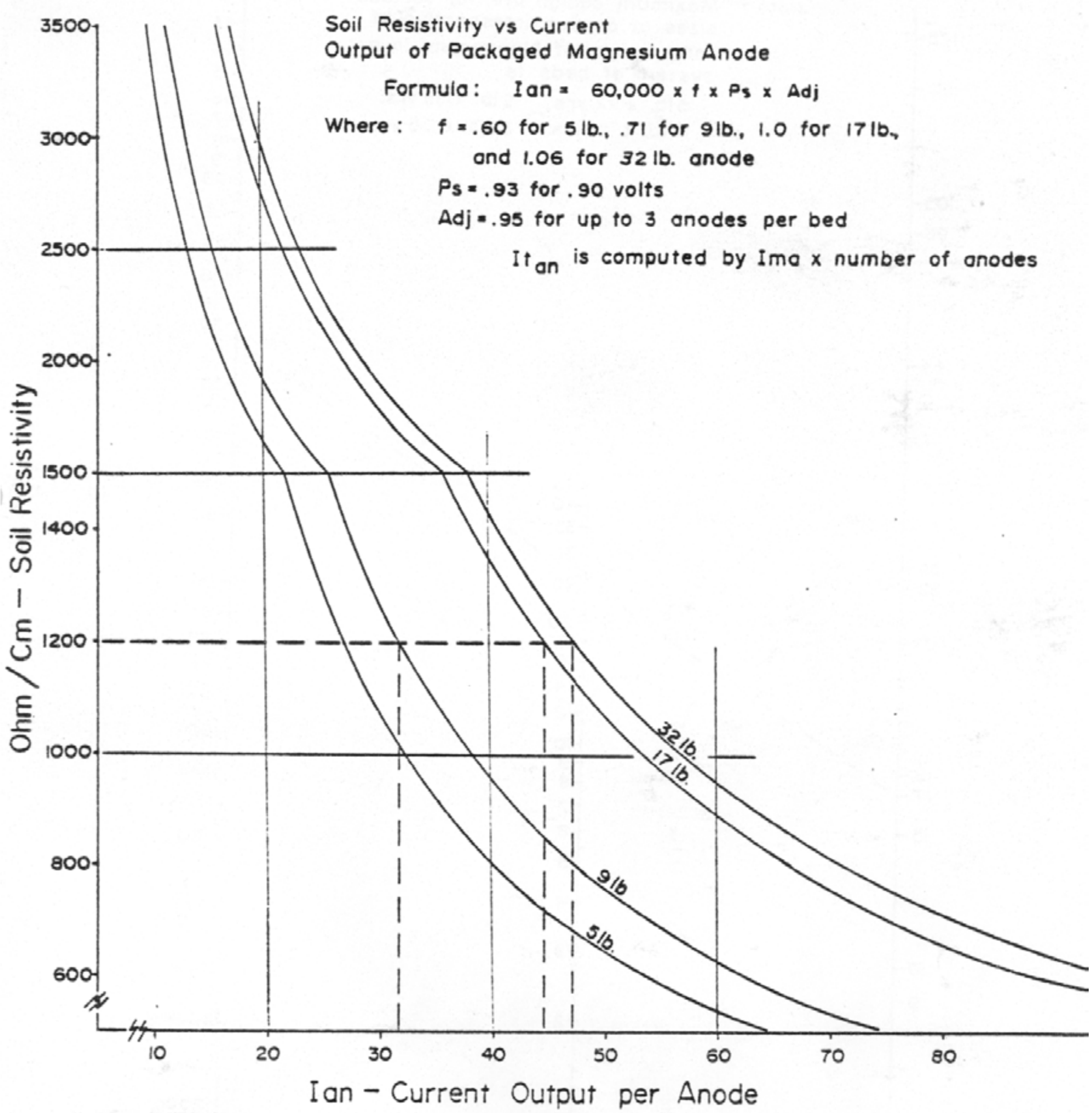
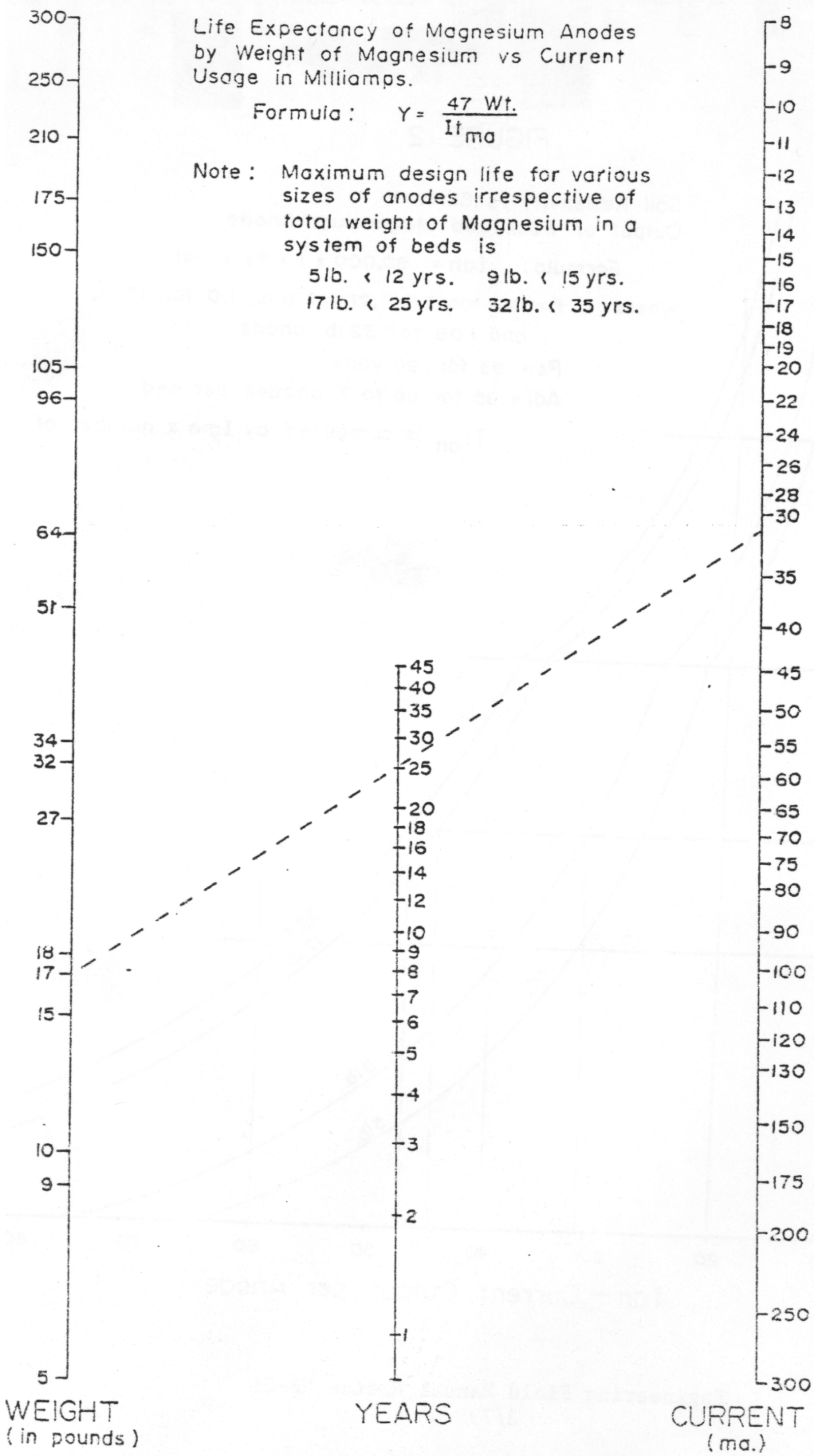

Soil Resistivity vs Current
Output of Packaged Magnesium Anode
Formula: Ian = 60,000 x f x Ps x Adj
Where: f = .60 for 5 lb., .71 for 9 lb., 1.0 for 17 lb., and 1.06 for 32 lb. anode
Ps = .93 for .90 volts
Adj = .95 for up to 3 anodes per bed
It an is computed by Ima x number of anodes
Ohm / Cm – Soil Resistivity
3500
3000
2500
2000
1500
1400
1200
1000
800
600
32 lb.
17 lb.
9 lb
5 lb.
10
20
30
40
50
60
70
80
Ian – Current Output per Anode

FIGURE 3


Life Expectancy of Magnesium Anodes by Weight of Magnesium vs Current Usage in Milliamps.
Formula : $Y = \frac{47 \text{ Wt.}}{It_{ma}}$
Note : Maximum design life for various sizes of anodes irrespective of total weight of Magnesium in a system of beds is
5 lb. < 12 yrs. 9 lb. < 15 yrs.
17 lb. < 25 yrs. 32 lb. < 35 yrs.
300
250
210
175
150
105
96
64
51
34
32
27
18
17
15
10
9
5
45
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26
28
30
35
40
45
50
55
60
65
70
75
80
90
100
110
120
130
150
175
200
250
300
WEIGHT (in pounds)
YEARS
CURRENT (ma.)